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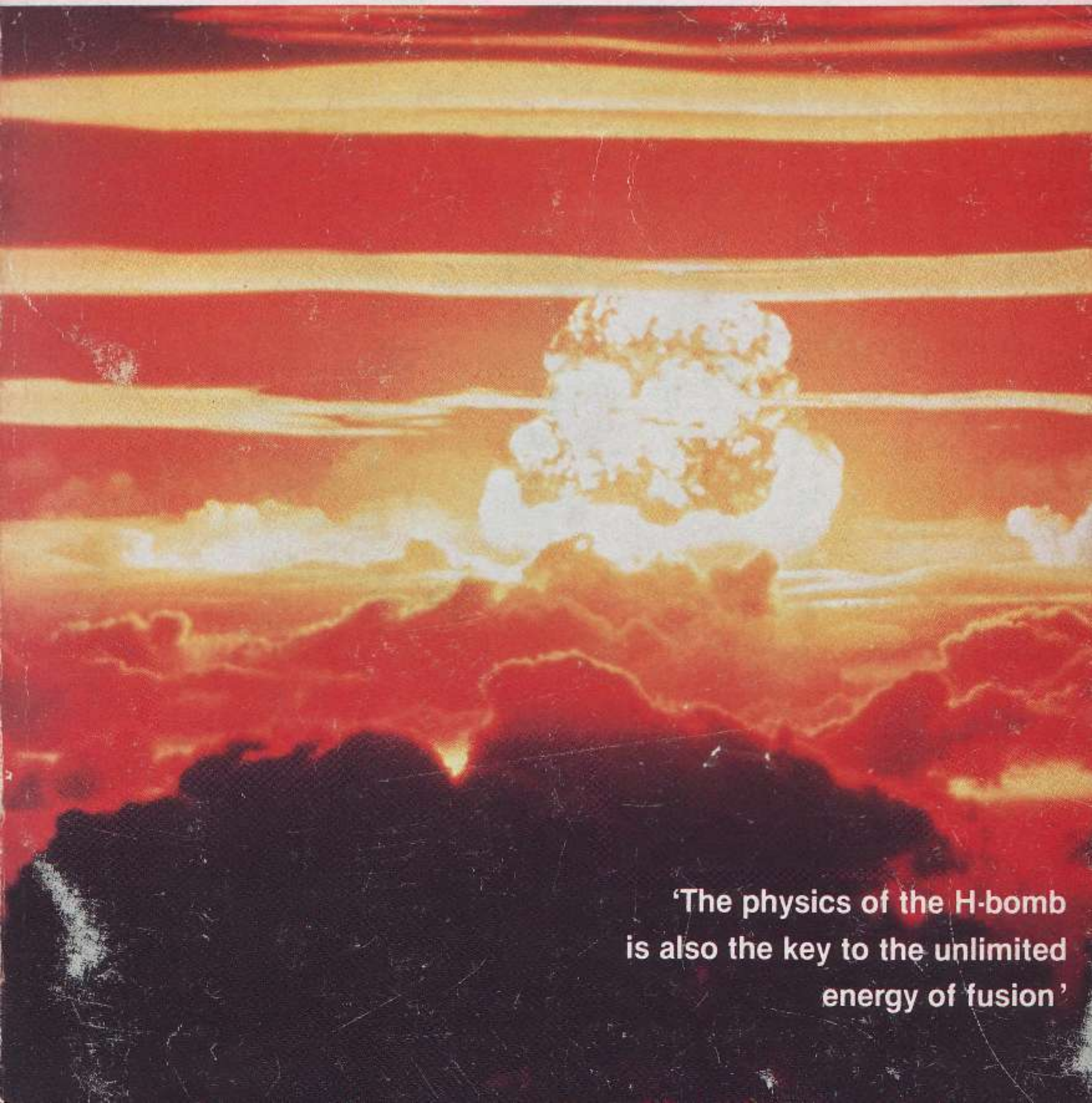
The Physical Principles Of Thermonuclear Explosive Devices



'The physics of the H-bomb
is also the key to the unlimited
energy of fusion'

Contents

Wernher Von Braun once said that we have invented rockets, not to destroy our planet, but to explore the universe. Similarly, we may say that we have discovered thermonuclear energy, not to destroy our planet, but to advance mankind toward a peaceful, galactic culture.

—*Dr. Friedwardt Winterberg*

bombs required to four. In the next chapter we shall show that by extrapolation of the same "trick" the number of required bombs can be reduced to just one.

Suppose that the detonation waves from four fission explosions behave like small-amplitude sound waves. Then the configuration shown in Figure 3, displaying a cross section in one plane of the tetrahedral assembly, would give a much better approximation to a spherical implosion wave. In it the four fission bombs are placed each at one focus of four ellipsoidal mirrors, formed by a heavy substance (e.g., lead), reflecting the waves. The second foci of these

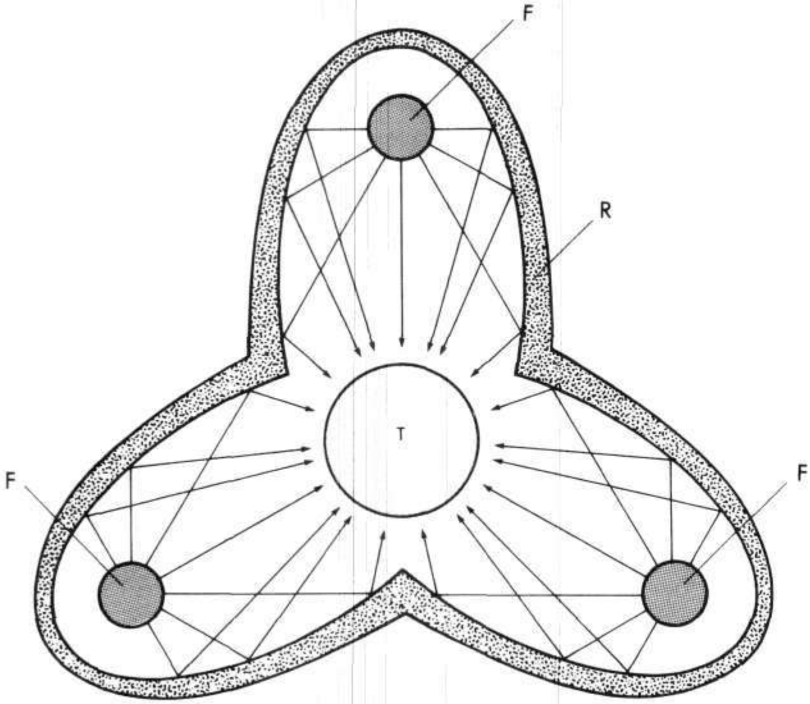


Figure 3. In the polyhedron-bomb ignition principle, several fission bombs are arranged around the thermonuclear explosive so that the shock waves from their simultaneous explosions will be reflected by the wave reflector R onto the thermonuclear explosive T positioned at the center of the tetrahedron. Shown here is a cross section in which only three of the four fission bombs appear.

CHAPTER EIGHT

Other Ignition Configurations

The configuration analyzed in the preceding chapter is a mirror-type shock wave focusing system, in effect. This suggests that the same result might be accomplished by a shock wave lens. It is easy to show that such a shock wave lens is, in fact, possible.

From the theory of plane shock waves it follows that for a given temperature T behind the shock front the propagation velocity of the shock wave is proportional to $A^{-1/2}$, where A is the atomic weight of the material through which the shock propagates. From this there follows a relative refractive index n for the shock wave propagating from a first medium of atomic weight A_1 to a second medium with atomic weight A_2

$$n = (A_2/A_1)^{1/2}. \tag{23}$$

If, for example, $A_1 = 1$—assuming that the first medium is filled with hydrogen gas—then a refractive index of $n = 2$ could be achieved by choosing a second medium with $A_2 = 4$ (e.g., helium gas). The still undetermined parameter of the density ratio ρ_2/ρ_1 for both mediums must be chosen to avoid a pressure jump that requires $p_2 = p_1$. This is necessary because if $p_1 \gg p_2$ the second medium would be blown away, or if $p_1 \ll p_2$ most of the incident shock wave energy would be reflected. Since $p = (1/2)\rho v^2$, the condition $p_2 = p_1$ then simply implies that

$$\rho_2/\rho_1 = A_2/A_1. \tag{24}$$

A configuration for shock wave focusing by such a lens is shown in Figure 5.

Next let us consider another useful focusing method that differs from the previous ones in that it permits the focusing of a cylindrical convergent wave. Such a configuration is especially useful for the ignition of a growing thermonuclear wave starting from the end of a fuel cylinder, as shown in Figure 6.

The fission explosive is placed at the vertex point of a flat, solid cone. The configuration is surrounded by a conical tamp as shown, with a gap between the outer cone surface and the inner tamp surface. The width of this gap space is chosen to be equal to the

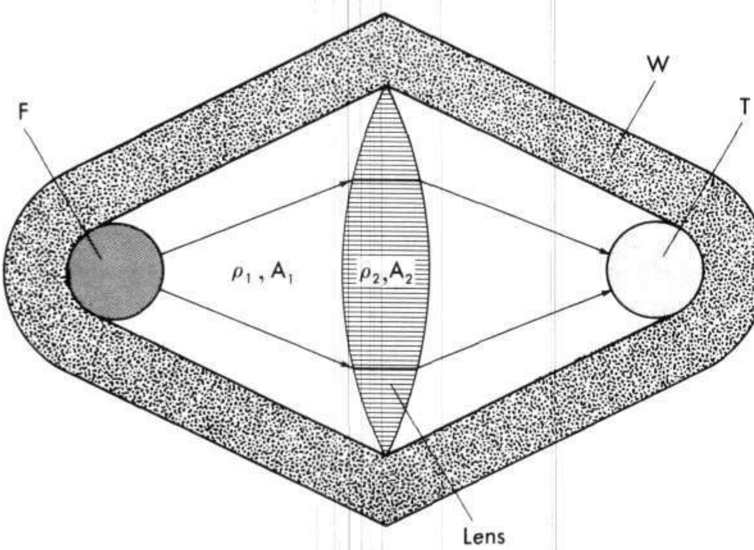


Figure 5. Shock wave focusing by a shock wave lens: the divergent shock wave from the fission explosive F is made convergent again by passing it through a medium of larger density acting as a lens. T is the thermonuclear explosive; W is the wall; ρ denotes density and A atomic weight.

diameter of the fission explosive. After the fission explosive has been detonated, a supersonic conical blast wave will then propagate from the vertex point of the cone to its base. At the base the supersonic blast wave can be rotated according to the theory of Prandtl-Meyer[8] by the angle

$$\beta \leq \beta_{\max}, \tag{25}$$

where

$$\beta_{\max} = \frac{\pi}{2}\left(\sqrt{\frac{\gamma+1}{\gamma-1}} - 1\right). \tag{26}$$

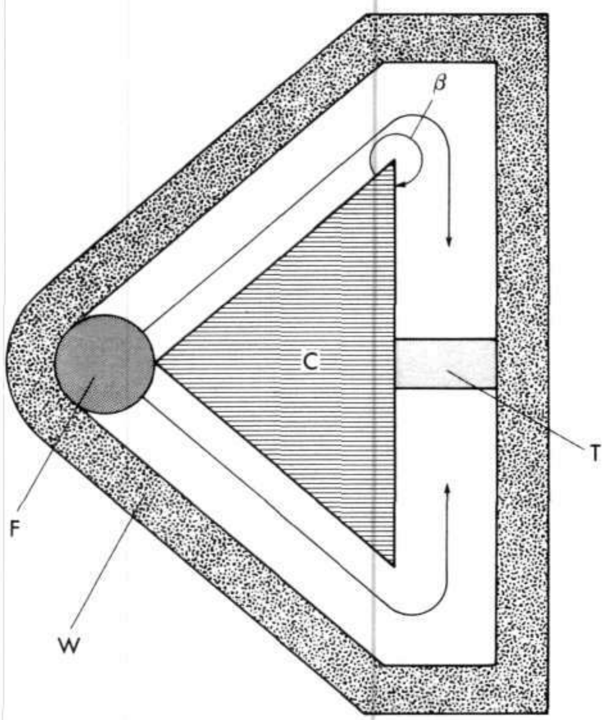


Figure 6. Cylindrical implosion by supersonic Prandtl-Meyer flow around the corner of a cone: the supersonic flow starting from the fission explosive F is here guided along the wall W and the outer surface of the cone C to generate a cylindrical implosion onto the thermonuclear explosive T.

Since the specific heat of the blast wave produced by the fission bomb is primarily from blackbody radiation, we may set the specific heat ratio $\gamma = 4/3$ and obtain

$$\beta_{max} \simeq 148^\circ.$$

This large number shows that one can make the cone rather flat.

After the conical blast wave has been rotated by the angle β, it will propagate as a cylindrical convergent wave along the base surface of the cone toward its axis. The thermonuclear fuel, having here the shape of a cylinder, would have to be positioned as shown in Figure 6.

The significance of this last configuration is that it shields the thermonuclear fuse optimally against the soft X-ray precursor of the exploding fission bomb. A disadvantage here is the cylindrical implosion geometry that results, rather than the optimal spherical configuration.

CHAPTER NINE

Multishell Velocity Amplification

As was previously pointed out, one of the problems in igniting a thermonuclear explosion in pure DD is the high ignition temperature, which is approximately 5×10^8 K, that is, ten times larger than the ignition temperature for the DT reaction. Such a high temperature should be attainable with the tetrahedral, four-fission-bomb ignition concept in conjunction with a Guderley convergent shock wave. The fact that the temperature in the Guderley case rises as $r^{-0.8}$ excludes the use of one fission bomb as the trigger.

There is, however, another configuration whereby a much larger temperature rise with decreasing radius is possible. This configuration makes use of the fact that in a series of elastic collisions of bodies decreasing in mass, the velocity toward the smaller mass is increased. If the mass ratio

$$m_{n+1}/m_n = \alpha$$

between elastically colliding bodies is constant, and the velocity of the first body with mass m_0 is v_0, then the nth body assumes the velocity after collision of

$$v_n = [2/(1 + \alpha)]^n v_0. \quad (27)$$

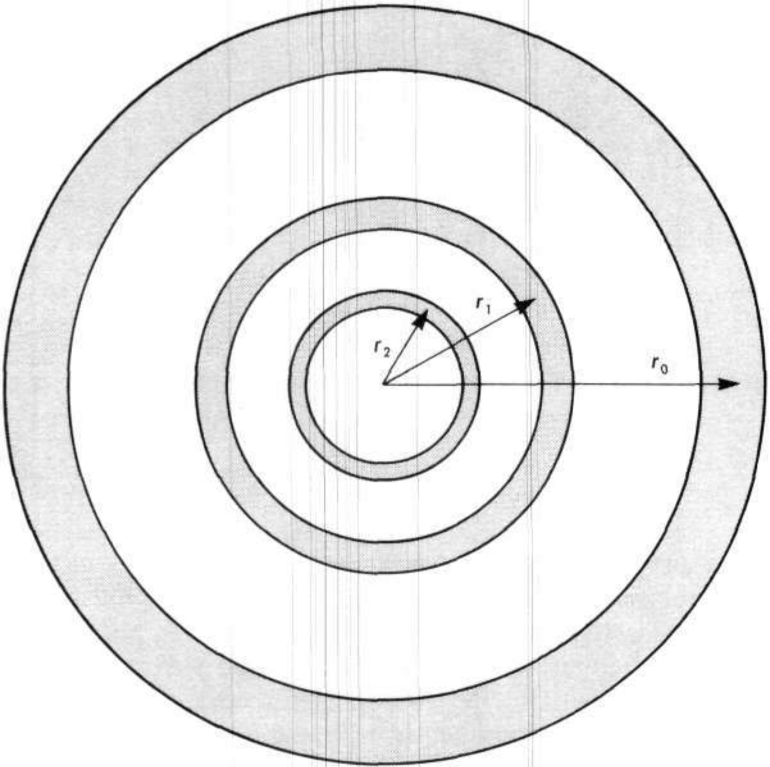


Figure 7. The implosion velocity can be raised through the subsequent collision of several concentric shells of decreasing mass.

We now make the special assumption that the subsequently colliding bodies are concentric spherical shells of radius r_n, having the mass

$$m_n = 4\pi\rho r_n^{\ 2} \cdot \Delta r_n, \tag{28}$$

where ρ is the density of the shell material and Δr_n is the shell thickness (see Figure 7). We further assume that the assembly of concentric shells is geometrically self-similar:

$$\Delta r_n = \varepsilon r_n, \qquad \varepsilon = \text{const} < 1. \tag{29}$$

We thus have

$$m_n = 4\pi\rho\varepsilon r_n{}^3 \tag{30}$$

and

$$\frac{m_n + 1}{m_n} = \left(\frac{r_n + 1}{r_n}\right)^3 = \alpha, \tag{31}$$

or

$$r_{n+1} = \alpha^{1/3} r_n. \tag{32}$$

We then put

$$r_n = r_0 f(n), \tag{33}$$

with $f(0) = 1$. Inserting this into Eq. (32) results in the functional equation for $f(n)$:

$$f(n + 1) = \alpha^{1/3} f(n). \tag{34}$$

With $f(0) = 1$, this functional equation has the solution

$$f(n) = \alpha^{n/3}. \tag{35}$$

We thus have

$$r_n = r_0 \alpha^{n/3}. \tag{36}$$

Eliminating from Eqs. (36) and (27) the parameter n we can express v_n in terms of r_n, that is, v as a function of r. Putting

$$a \equiv -\frac{\log\,[2/(1 + \alpha)]^3}{\log \alpha}, \tag{37}$$

we find

$$v_n/v_0 = (r_0/r_n)^a, \tag{38}$$

or, simply,

$$v \propto r^{-a}. \tag{39}$$

The temperature generated by a shell with a velocity v rises in proportion to v^2, hence

$$T \propto r^{-2a}. \tag{40}$$

We take as an example $\alpha = 1/2$ and find $a = 1.25$, hence $2a = 2.5$. It thus follows that a convergent multishell "wave" gives a temperature rise as a function of r with an exponent roughly three times larger than in the Guderley case. Therefore, by starting with a spherical wave at $r_0 = 5$ cm, a threefold velocity amplification is already reached at $r = 2$ cm. The number of shells needed is five since for $\alpha = 1/2$ and $v_n/v_0 = 3$ one computes from Eq. (27) that $n = 4$. In particular, $r_1 \simeq 4$ cm, $r_2 \simeq 3$ cm, $r_3 \simeq 2.5$ cm, and $r_4 \simeq 2$ cm. The threefold velocity amplification is accompanied by a $3^2 \sim 10$-fold rise in temperature. Actually, the temperature rise will be less dramatic because the collisions between the shells will be inelastic. This necessitates making r_0 larger and increasing the number of shells. Alternatively, one may make the inner shells out of fissile material that would become critical upon compression. This would compensate for any losses and could result in an even more rapid temperature rise.

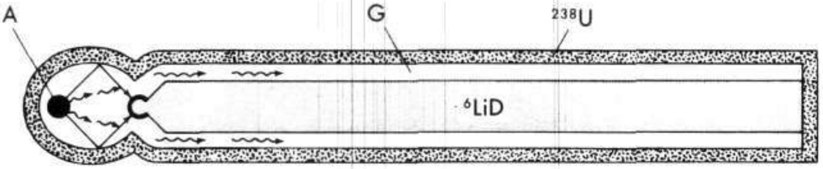


Figure 16. H-bomb using the autocatalytic principle, in which the atom bomb A sends soft X-rays through the gap G between the ^{238}U liner and the ^{6}LiD thermonuclear fuel.

which turns out to be of the right order of magnitude as required for isentropic high-density compression.

Figure 16 shows one possible way in which this concept can be incorporated into a complete weapons design.

The second alternative to generate a precursor precompressing the thermonuclear fuel in front of the detonation front is by using the large neutron flux released from the burn zone. The principle of this idea is shown in Figure 17, where F is the material surrounding the fuel assembly that serves as a tamp but, in addition, also reacts with neutrons. Here there is no need for a gap space as required for the soft X-ray precursor. The material F can consist of some light material with a large neutron cross section, for example, ^{6}Li, ^{9}Be, or ^{10}B. Boron-10 has the advantage that it is abundant and cheap. Of course, F may also consist of fissile material.

The number of neutrons produced in the burn zone per unit time and volume is given by

$$\dot{Q} = (n_1{}^2/4)\langle\sigma v\rangle = 4n_0{}^2\langle\sigma v\rangle. \tag{86}$$

To estimate the neutron flux on the surface of the detonation front, we shall assume that the neutrons are emitted from a fuel cylinder of equal height and diameter. That this assumption is reasonable can be seen as follows:

The inertial confinement time of the compressed fuel cylinder is of the order $\tau \simeq r/a_s$, where

$$a_s = \sqrt{10kT/3M}$$

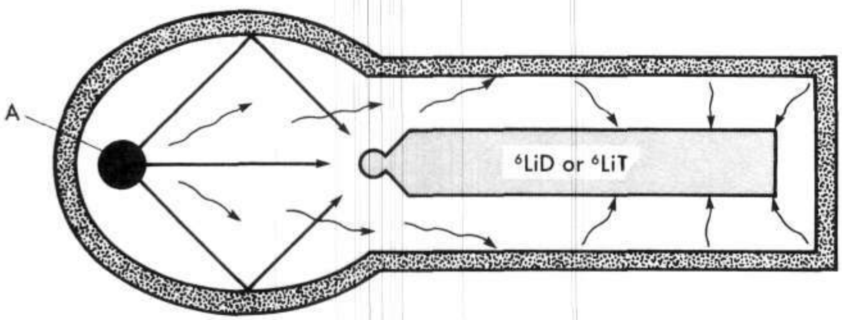


Figure 18. Compact H-bomb or neutron bomb in which the thermonuclear fuel is simply precompressed by the soft X-rays without using the autocatalytic principle.

of the autocatalytic principle. This concept is shown in Figure 18. This design is meaningful only for rather small fuel cylinders.

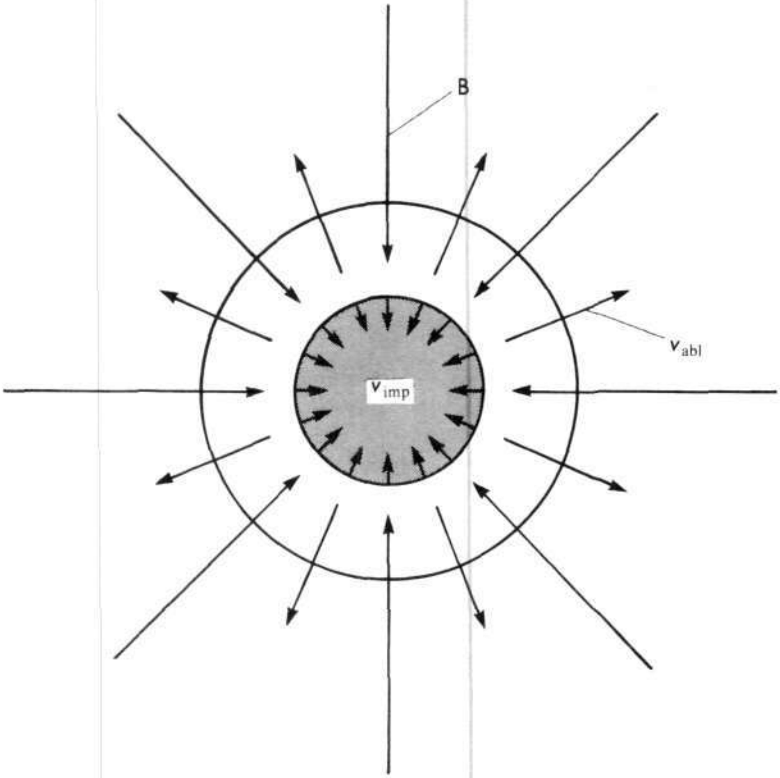


Figure 22. Ablation implosion of thermonuclear target bombarded by beams B (either laser or charged particles) from many sides. v_{imp} is the implosion velocity, and v_{abl} is the ablation product velocity.

Figure 22 shows the beam ignition principle with several beams used to bombard the thermonuclear explosive from several sides. The beams hitting the spherical thermonuclear target surface make it ablate. The recoil from this ablation causes a rocketlike implosion of the target.

The ignition concept using just one beam is explained[12] in Figure 23. Here the same principle of shock wave focusing by a curved wall that we encountered in the concept of igniting a thermonuclear explosion by a fission bomb is used. In the case of a laser beam the focusing can be done by a parabolic mirror.